

Biodiversity and its fragility in Yunnan, China

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Abstract: In Yunnan, 8 major aspects of biodiversity and fragility in landforms, ecosystems, distribution populations, alien invasion, segregation, pollution and maladministration with various menace factors causing biodiversity loss have been described. It is revealed that the facts that the biodiversity and fragility coexists in this paper. Accordingly, 6 major countermeasures for effective conservation and rational utilization of the provincial biodiversity were suggested on the basis of the scientific development concepts, principles of nature protection, conservation biology, resource management and ethnobotany and present status in Yunnan with rich intangible resources such as climatic, ethnical and cultural diversity, etc.

Keywords: Biodiversity; Endemism; Fragility; Conservation; Countermeasures; Yunnan

Introduction

Biodiversity is the variety of life in all its forms, levels and combinations, including ecosystem diversity, species diversity, and genetic diversity. Since biodiversity possesses not only direct and indirect value, but also ecological, cultural, and economic value, it supplies the environment for human existence and development to adapt the changes of regional and global environments in the long run. It is believed that the higher biodiversity level man has, the more options he possesses for his future development and generations.

It was reported by FAO in World Forest Facts, however, that some 11.3×10^6 hm² of the world forest areas were totally destroyed, and another 18×10^6 hm² of valuable tropical rainforest areas of the world were annually damaged to some extent. A report from UNEP also said that 12% of mammals and 11% of birds in the world were endangered of extinction and some 150–200 species disappeared every day. IUCN also reported that 233 species of primates were confronted with serious challenges for existence, and over 50% of apes, lemurs, macaques and lorises were on the verge of extinction (Qian 1993, 1998). Although the global area of plantations has increased, the rapid decrease of primeval forest area is continued with an annual loss of 6×10^6 hm² from 2000 to 2005, and on average, 5 percent of the native tree species to a country are in the vulnerable, endan-

gered and critically endangered species according to the forest resource assessment (FRA) made by FAO in 2005. Today when man is faced with the global forest reduction and ever-increasing aggravation of ecological fragility, biodiversity is gradually lost and its conservation is confronted with potential crises as forests are exposed to the effects of poor management and unbridled development. It is, therefore, urgent that biodiversity and fragility and major conservation countermeasures should be studied for the effective biodiversity conservation in Yunnan since it is a specific area with top priority of global significance. Based on the background investigations so far, Yunnan's biodiversity fragility is intensively and systematically studied to lay reliable scientific bases for effective conservation of the biodiversity and sustainable development in Yunnan.

Biodiversity

The specific characteristics in topography, climates and physical environment turn to the most abundant biodiversity and endemism for Yunnan, which evolves abundant ecosystems, forest types, wildlife resources and endemic species, including many precious epibiotic and relic species.

Biodiversity in ecosystems

Including forest ecosystems, shrub ecosystems, meadow ecosystems, wetland ecosystems, wilderness ecosystems, etc., Yunnan harbors almost all types of major terrestrial ecosystems of the world. Its 6 major river systems and over 30 plateau-lakes compose a basic structure of the freshwater ecosystems, showing the particularities of such ecosystems in China.

In Yunnan complex specific geographical environment and diverse climatic types evolve 30 ecosystems (Guo *et al.* 1998) from the low basins of the tropics in the south to the deep narrow valleys of the alpine areas in the northwest. Among the 30 ecosystems, Yunnan has the most abundant and diverse forest ecosystems that include 6 rainforest ecosystems, 6 broad-leaved forest ecosystems, 4 coniferous forest ecosystems, 3 shrub eco-

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systems and some other ecosystems of coppices, bamboos, wildernesses, meadows, wetlands, plantations and so on. The 6 rainforest ecosystems are humid rainforest ecosystem, monsoon rainforest ecosystem, montane rainforest ecosystem, semi-evergreen seasonal rainforest ecosystem, deciduous monsoon rainforest ecosystem, and limestone monsoon rainforest ecosystem. The 6 broad-leaved forest ecosystems include monsoon evergreen broad-leaved forest ecosystem, semi-humid evergreen broad-leaved forest ecosystem, mid-montane dominant evergreen broad-leaved forest ecosystem, montane mossy evergreen broad-leaved forest ecosystem, sclerophyllous evergreen broad-leaved forest ecosystem and deciduous broad-leaved forest ecosystem. The 4 coniferous forest ecosystems comprise warm-torrid coniferous forest ecosystem, warm-temperate coniferous forest ecosystem, temperate-cool coniferous forest ecosystem and cold-temperate coniferous forest ecosystem. The 3 shrub ecosystems consist of limestone shrub ecosystem, xerothermic river-valley shrub ecosystem and tropical flood-land shrub ecosystem. There are also culmen mossy coppice ecosystem, bamboo forest ecosystem, high-and-cold-wilderness ecosystem, alpine meadow ecosystem, river-upland bog-lake wetland ecosystem, farming-forestry-animal-husbandry plantation ecosystem and so on.

Biodiversity in forest types

In the above forest ecosystems, there are rich forest types, including some endemic ones, from the low tropical rainforests in the south to the cold alpine coniferous forests in the northwest in Yunnan. As the principal parts and major shelters of terrestrial ecosystems, 114 forest types in 30 ecosystems with trees as dominant species, co-dominant species, or characteristic species are found in Yunnan, making up 53.8% of that in China and ranking the first of the country. They are representatives of most terrestrial ecotypes rich in wildlife of tropics, subtropics, temperate regions and frigid zones and alpine vegetation types or forest types of bamboos, woods, steppes, meadows, savannas as well as mountain tundras, and each of them consists of several climatic or edaphic types.

Almost all the major forest areas in the province consist of abundant vegetation types that house rich wildlife. In the Xishuangbanna Nature Reserve alone, for example, there are 8 very important vegetation types such as tropical rainforests, tropical monsoon forests, subtropical broad-leaved evergreen forests, broad-leaved deciduous forests, temperate coniferous forests, bamboo forests, shrub forests and herbosa, under which there are altogether 13 subtypes and 29 formations. The above forests harbor over 3 500 species of higher plants, 700 species of higher animals and 1 500 species of insects (Xu *et al.* 1987). The number of these species makes up 21% of the total of species in Yunnan, 13% of that of China, 40.3% of the total of Yunnan and 24% of that of China, and 15% of the total of Yunnan or 6% of that of China, respectively (Pu *et al.* 2001).

Biodiversity in wildlife species

In the above ecosystems and forest types, Yunnan has over 18 000 higher plant species, 15 000 angiosperm species, 100 gymnosperm species, 1 500 fern species, 1 500 bryophyte species, 800 freshwater algae species and 250 bamboo species (Hui *et al.* 2003; Hu *et al.* 1998). They make up 51.6%, 50.5%, 37.0%, 57.7%, 68.2%, 8.9% and 50% of the total species of China, re-

spectively (The State Environmental Protection Administration of China 1998; Yang *et al.* 2004). Among more than 15 000 seed plants, there are 151 species were listed in the national priority protection species, i.e., 42.6% of that of the state. There are 1 836 vertebrate species, 304 mammal species, 810 bird species, 170 reptile species, 120 amphibian species, 12 000 insect species, and 432 freshwater fish species, accounting for 54.8%, 49.6%, 65.1%, 45.2%, 42.3%, 23.5% and 54.0% of that of the country, respectively. Among the 335 wild animal species of national priority protection, Yunnan has 243, i.e., 72.5% of that of the country. Among all the wild animal species listed above, many species are endemic to Yunnan, for example, 290 freshwater fish species in 40 genera in 5 families, 46 mammals under the first-class national protection including *Bos gaurus*, *Elephas maximus*, *Panthera tigris* corbeti, *Rhinopithecus bieti*, *Nycticebus intermedius*, *Hyltobates leucogenys*, etc., and 154 species under the second-class national protection including *Macaca assamensis*, *Ailurus fulgens*, *Pavo muticus*, *Manis pentadactyla*, etc. Based on the background surveys of the forest resources and the major factors of the biodiversity in this special province are systematically studied in order to show the rich biodiversity and great conservation value. The major ways for the biodiversity conservation in Yunnan are described in 4 aspects, i.e., the biodiversity and endemism in ecosystems, vegetation types, wild animals, and genetic resources (Table 1). It can clearly be seen that the species richness value, endemism value and endemism rate rank the first in China (WWF 1996).

Table 1. The number of known wildlife species in Yunnan, China and the world*

Taxa	Species in Yun- nan	Species in China	Species in the world	Yunnan/ China (%)	Yun- nan/the world (%)
Mammalia	304	581	4181	52.3	7.3
Aves	810	1244	9040	65.1	9.0
Reptilia	170	376	6,300	45.2	2.7
Amphibia	120	284	4010	42.3	3.0
Insecta	12000	51000	920000	23.5	1.3
Pisces (Freshwater)	432	800	21400	54.0	2.0
Pisces (total)	432	3862		11.2	
Angiospermae	15000	30000	260000	50.0	5.8
Gymnospermae	100	270	900	37.0	11.1
Pteridophytes	1500	2600	12000	57.7	12.5
Bryophytes	1500	2200	23000	68.2	6.5
Freshwater algae	800	9000	25000	8.9	3.2
Bamboos	250	500	1000	50.0	25.0

Notes: *The species data are originally adopted from the reports of China's Biodiversity, which is A Country Study published by the State Environmental Protection Administration of China in 1998.

There are 270 gymnosperm species in 34 genera in 10 families in China and about 900 species in 79 genera in 15 families all over the world, while Yunnan alone has 100 species in 32 genera in 10 families. Among the 100 species, 36 are listed in the 63 national rare endangered gymnosperm species and 21 are endemic to this province. The 21 endemic species include *Cycas pectinata*, *C. siamensis*, *Keteleeria xerophila*, *Pseudotsuga forrestii*, *Tsuga forrestii*, *Pinus wangii*, *Podocarpus flearyi*, *Cephalotaxus oliveri*, *C. anceolata*, *Taxus yunnanensis*, *Amentotaxus yunnanensis*, *Torreya yunnanensis* and so on.

Yunnan holds 15 000 angiosperm species in 1 953 genera in 230 families, amounting to 50%, 64.9% and 79.1% of the total species, genera and families, respectively. Calculated according to the abundance rate, i.e., the percentage of wildlife species number per square kilometer (WWF 1996), the abundance rate of the seed plants here is 3.81, ranking second only to Malaysia's 4.55 in the Northern Hemisphere. The richness rate of Yunnan Province is 7.9 times of that (0.48) of India and 11.9 times of that of whole China.

It is also rich in fern plant species, over 1 500 species in 198 genera in 59 families in all. Among the 1 500 species existing here, there are numerous endangered species and endemic species such as *Archangiopteris henryi*, *Sorolepidium glaviale*, etc. 20 species in the rare endangered species of the national priority protection include *Isoetes japonica*, *Ophioglossum thermale*, *Atsophila spinulosa*, *Christensenia assamica*, *Sinopteris grevilleoides*, *Archangiopteris henryi*, *Sorolepidium glaviale*, *Neocheropteris palmatopedata*, *Piatyterium wallichii*, etc. (Guo *et al.* 1998).

Biodiversity in endemic plants

A notable biodiversity feature in plant resource in Yunnan is its endemism. As a result, Yunnan has become a high-frequency region of endemic plant emergence in China. Among China's 243 endemic genera of seed plants (Chen 1993), there are 180 genera distributing in Yunnan, making up 74.1% of the total, and 30 genera are endemic to Yunnan alone (Wang *et al.* 1994). There are even more abundant endemic species in Yunnan. Xishuangbanna in Southwestern Yunnan has 153 rare endemic species of the tropics. Northwestern Yunnan houses enormous quantities of coniferous species, endemic components, alpine rhododendron species and alpine bamboo species of the cold-temperate Hengduanshan Mountains where endemic seed plant species account for over 30% of the total (Guo *et al.* 1998), thus becoming one of the three well-known centers of endemic plants in China (Chen 1993). Southeastern Yunnan preserves a considerable number of paleophyte families and genera of tertiary relics, and epibiotic plant species, such as *Manglietia*, *Manglietiastrum* and so on, which are supposed to be the most primitive. In this specific area of Yunnan, there are quite a few monotypic families, oligotypic families, oligotypic genera, monotypic genera or auto-genera, including *Tsoongiodendron*, *Craigia*, *Diplopanax*, *Alcimandra*, *Dipentodon*, *Amentotaxus*, *Fokienia*, *Calcareoboea*, *Manglietiastrum* Law, *Lagarosolen*, *Parepigynum*, etc., becoming another one of the three well-known centers of endemic plants of the country.

Biodiversity in endemic animals

In sum, Yunnan houses 1 836 vertebrate species, 304 mammal species, 810 bird species, 170 reptile species, 120 amphibian species, 12 000 insect species, and 432 freshwater fish species, i.e., 54.8%, 49.6%, 65.1%, 45.2%, 42.3%, 23.5% and 54.0% of that of the country, respectively. Among the 335 wild animal species of national priority protection, Yunnan has 243, making up 72.5% of that of the country. Yunnan has 46 mammal species under the first-class national protection such as *Bos gaurus*, *Elephas maximus*, *Panthera tigris* Corbeti, *Rhinopithecus bieti*, *Nycticebus intermedius*, *Hyltobates leucogenys*, etc. and 154 species under the second-class national protection, involving *Macaca assamensis*, *Ailurus fulgens*, *Pavo muticus*, *Manis pentadactyla*, etc.

The investigations and statistics showed that approximately 15% of the total terrestrial vertebrate animal species in China are endemic to Yunnan (Guo *et al.* 1998). Among the 15 primate species protected by the country, there are 10 species distributing in Yunnan, all of which belong to those under the first-class national protection. One of them is the endangered *Rhinopithecus bieti* (merely 1700 in 15 populations altogether) that are as rare and famous as *Ailuropoda*, only distributing in the cold-temperate coniferous forests of spruces and firs of the Baixueshan Mountains with an elevation of over 3500 meters in northwestern Yunnan. Among 10 gibbon species all over the world, China has 4, *Hyltobates concolor*, *H. hoolock*, *H. leucogenys* and *H. lar*, all of which distribute in the tropical forests in southern Yunnan with a sole exception that *Hyltobates concolor* can also be found in the Hainan Island (Yang *et al.* 1999). The 26 animal species under the first-class national protection such as *Macaca nemestrina*, *Nycticebus intermedius*, *Tragulus javanicus*, *Bos gaurus*, *Arctictis binturong*, *Helarctos malayanus*, *Panthera tigris corbeti*, *P. t. Tigris*, *Elephas maximus* and so on distribute only in Yunnan within China. Among the 1 836 vertebrate animal species distributing in Yunnan, 66 beast species, 112 bird species, 8 reptile species, 40 amphibian species and 290 freshwater fish species are endemic or distribute only in Yunnan. Among the 1 224 bird species recorded in China, 112, including *Pavo muticus*, *Polyplectron bicalcaratum*, *Crus antigone*, *Lophophorus sclateri*, *Syrnaticus humiae*, etc. distribute in Yunnan only. Among the 40 amphibian species, more than 20 species, including *Ichthyophis bannanica*, *Tylotriton verrucosus*, *Rana verrucosipinosa*, *Cuora yunnanensis*, *Manouria impressa*, etc., are rare endemic species in Yunnan (Yang *et al.* 1992). The 432 freshwater fish species are recorded in Yunnan, i.e., 54.0% of the total in China. Among them, 290 species such as *Schizothorax taliensis*, *Sinocylocheilus grahami grahami*, *Cyprinus pellegrini pellegrini*, *Anabarilius graham*, *Anguilla nebulosa nebulosa*, etc. are endemic to Yunnan, and almost in every river or lake hereabout, endemic species can be found.

Biodiversity in genetic resources

Besides, Yunnan is abundant in genetic diversity. Many wild types and kindred species of the economic cultivars and domestic animals can be found in Yunnan. All the 3 wild rice species *Oryza sativa* *spontanea*, *O. Meyeriana*, *O. officinalis* found in China are distributed in the marginal zone of the tropics from the south to the southwest of Yunnan. Many wild types and kindred species of many major cultivars at home, including *Litchi chinensis*, *Actinidia chinensis*, *Camellia sinensis* var. *macrophylla*, *Artocarpus lakoocha*, *Mangifera sylvatica*, etc. are mainly distributed in Yunnan (Wu *et al.* 1980). The wild types and kindred species of domestic animals distributed only in Southern Yunnan in China include *Bos gaurus*, *B. Javanicus*, *B. Frontalis*, *Gullus gallus*, *Tadorna ferruginea*, etc. Some domesticated cows, buffaloes, horses, pigs, goats, etc. and native here also belong to the endemic genetic resources that are of great importance for local economic increase.

Appraisals

From what have been described above, it can be seen that Yunnan holds the richest biodiversity in China, becoming a rare gene bank of wildlife species, an excellent habitat and a natural refuge

for both wild plants and animals with many rare epibiotic and relic species as well as valuable endemic genetic resources. That is why Yunnan has generally been acknowledged to be a “Kingdom (Realm) of Wildlife” and famous for its peculiar biological abundance and endemism.

Spearheaded by Cai *et al.* since 1930s, the wildlife resources were basically investigated, floras preliminarily divided (Wu *et al.* 1957), and biodiversity researches widely made (Cai *et al.* 1978; Konta *et al.* 1990; Liu *et al.* 1992; Liu *et al.* 1993; Xu *et al.* 1995; Wu *et al.* 1996; Wu 1997; Long *et al.* 1998; Guo *et al.* 1998; Wang *et al.* 2000; Pu *et al.* 2001; Yang *et al.* 2004; Gao 2005). Further investigations were gradually conducted to update the background data of various nature reserves, including that of Xishuangbanna (Xu *et al.* 1987), the Gaoligongshan Mountains (Xue *et al.* 1995), the Nangun River (Yang *et al.* 2004), etc. Specific studies were profoundly carried out on the avifauna of Xishuangbanna (Yang *et al.* 1990), bamboo resources (Xue *et al.* 1995), *Dipterocarpus* forests (Yang *et al.* 1997), biodiversity conservation and sustainable development in biosphere reserves (Jiang *et al.* 1998), bamboo diversity and traditional uses (Yang *et al.* 2004), etc.. Theoretic researches were systematically made in the vegetation of Yunnan (Wu *et al.* 1987), the symposia on Yunnan's biodiversity (Wu 1993), Yunnan's forests (Xue *et al.* 1986), the plants in the Gaoligongshan Mountains (Li *et al.* 2000), ecological biology of rare and endangered tree species in Yunnan (Zhang 1998), the endemic *Rhododendron* plants in the Gaoligongshan Mountains (Dao *et al.* 1999), valuable plant germplasm resources (Abelson 1991) such as dragon blood plants (Cai *et al.* 1978), rare epibiotic species (Pu *et al.* 2001), etc. The significance of Tibetan sacred hills in nature conservation of Shangri-La Gorge was analyzed (Zou *et al.* 2005). The socio-cultural value in ethnobotany was probed (Long *et al.* 1994). The biodiversity management and utilization of ethnical traditional cultures of the Dai, Bulang, Jinuo and some others were summarized (Liu *et al.* 1992; Liu *et al.* 1993; Xu *et al.* 1995; Wu 1997; Long Chunlin *et al.* 1998; Wang *et al.* 2000; Konta *et al.* 1990). All these academic achievements have laid good foundations for better biodiversity utilization and conservation in Yunnan.

By the end of 2004, 193 nature reserves of various classes have been established in Yunnan, covering 3 473 000 hm², i.e., 8.8% of total area of the province (Gao 2005), ranking the first in China. Out of the 193, there are 13 national nature reserves, among which the Xishuangbanna Nature Reserve and the Gaoligongshan Nature Reserve have been listed by UNESCO in the Man and Biosphere Program (Jiang *et al.* 1998; Zhao *et al.* 1999). Besides, more than 10 wildlife domestication or reproduction centers and over 10 botanical gardens or arboretums for cultivating and protecting the rare endangered plants have been established.

In Yunnan biodiversity still coexists with its evident fragility characterized by many menaces though biodiversity preservation has been improved to some extent. It is, therefore, urgently necessary that the biodiversity and fragility in Yunnan be intensively and systematically studied together with the researches on the nature reserves, species resources, species compositions in endemic genera, ecosystems and genetic resources by investigating the threat factors of biodiversity and ecological fragility mechanism.

Fragility

Despite evident abundance and endemism as well as the above achievements and establishments, in Yunnan, biodiversity is still faced to serious menace because of its scattered populations with few individuals, narrow distribution areas, poor ecologic adaptability, and extreme sensitivity and fragility to various disturbances caused by topographic, geologic, geographic, and socio-economic factors, including the rapid expansion of the human population, fast consumption of the natural resources, gradual narrowing of agriculture, forestry and fishery production, serious pollution of the environment (Xu 2002), harmful alien species invasion, etc. The serious menace to the biodiversity has resulted in degradation, segregation and disintegration of the ecosystems, islandization and fragmentation of the habitats, diversity reduction of the domesticated animals and cultivars (Gao 2005).

Upon careful analyses, biodiversity and fragility is intensively and systematically studied to reveal the following 8 kinds of primary fragility characteristics.

Fragility in landforms

Though it is one of the 4 major forest areas in China, Yunnan has only 24.2% of forest cover percentage, and it is characterized by its steep mountainous landforms with slopes and bare topsoil in most parts. Without the shelter of forests and related vegetation because of deforestation, the bare topsoil on the steep slopes runs off very easily when facing heavy rains and mountain currents, thus resulting in soil erosion, land mass movements, ecological aggravation of whole valleys, or regional deterioration of habitats. It is usually more difficult to restore vegetation covers in such aggravated mountainous areas than that in basins. Once a forest is destroyed and the topsoil is rushed down, the species is totally lost.

Fragility in ecosystems

Since the ecosystems in Yunnan have their systematic components and structures with high specialization, they are weak in anti-interference. In fact, many of such ecosystems are always fast in material circulation and high in sensitivity because over 2/3 of them are in the tropics and southern subtropics. In the humid and hot environment, both material cycle and energy flow of the tropical ecosystems are very fast. The ecosystems, therefore, are highly sensitive to both the environmental changes and disturbances from the outside. As a result, the stability of the ecosystems is poorer than that of the ecosystems in other climatic zones.

Fragility in distribution

Characterized by both of its abundance and clear marginal distribution, biodiversity in Yunnan has edge properties in biogeographic distribution, and these properties determine the fragility in adaptation of biological groups (Ma *et al.* 1998; Wang *et al.* 1985; De Walle *et al.* 1983). Marginal areas possess the edge effects of abundant biological groups (Xu 1996; Morgan *et al.* 1982; Wales. 1992) but the biological groups dispersed in an edge area are evidently fragile to adapt to the edge environment because edge areas are no longer the optimal distribution areas to

them, compared with those distributed in the central areas.

Fragility in populations

In Yunnan, wildlife populations are relatively small with fewer individuals. Its geographical complexity and diversity limit the ranges of the relatively consistent habitats. The different habitats in a same region vary greatly. These situations are very beneficial to differentiation and formation of new species, but not to dispersion and development of the populations. Under such circumstances, the wildlife populations are narrowly distributed, forming evident specificity. No matter whether one species moves horizontally or vertically in its environment space, it will soon find the physical conditions change tremendously. The populations have very limited ranges of their adaptive environment hereabout, and they have, in turn, formed their strong specificity with narrow adaptive zones in their evolutionary process.

Fragility by alien invasion

Just contrary to the above situations, alien invasion easily and frequently occurs in this specific region because of its diversified habitats that are also extremely adaptive to them. Among the harmful invasive species, crofton weed (*Eupatorium Adenophorum* Spreng) and water hyacinths (*Eichhornia crassipes*) are the most harmful ones that seriously damage the local ecosystems whereas vegetable leafminer (*Liriomyza sativae* Blanchard) greatly threatens the agricultural ecosystems. Owing to the blind introduction of more than 10 fish species including silver fish (*Protosalanx hyalocranius*) and 4 domestic carp species, one third of Yunnan's fish species have been endangered of extinction, and the rate of the endangered species in the plateau lakes is about two thirds. Taking Lake Dianchi for example, the remaining 2 fish species at present have an evident decline in population size compared to the 25 original ones, almost being replaced by the lake fish ecosystems in the middle and lower reaches of the Changjiang River.

Fragility by segregation

Human disturbances and destruction incurred to the forests have frequently caused reduction and deterioration of the habitats. The biodiversity conservation confronts with challenges due to the high frequency forest fires, attacks of forest pests, irrational construction and over-dependence of local residents on forest resources. Fuel wood consumption, slash-and-burn agriculture, illegal reclamation of forested lands, irrational logging, overgrazing, excessive fishing, illegal mining, and poaching of wild animals have become major impediments to effective biodiversity conservation, and the biodiversity and species habitats have been gradually lost as forests are exposed to human disturbances and overexploitation because of their socioeconomic activities. These have directly caused serious segregation, soil and water erosion, dried-up rivers and lakes as well as marsh shrinkage, thus greatly narrowing the habitats and causing the rapid loss or even extinction of the species (Pu *et al.* 2001). Only 30 out of the 105 original distribution areas of wild rice species in Yunnan were preserved according to the field survey in 2003 while the original wild rice species were extinct in the other 75 areas. Together with 10 newly-found distribution areas of *Oryza granulata* Nees et Arn.ex Hook. f., there are merely 40 areas left in the province, i.e., 1 for *Oryza rufipogon* Griff, 2 for *Oryza officinalis*

Wall.ex Watt, and 37 for *Oryza granulata* Nees et Arn.ex Hook. f. Besides, at least 5 000 to 10 000 leopard furs were annually exported from Yunnan in both 1960s and 1970s, but there are very few leopards now (Gao 2005). It can be seen from above that man's overexploitation has resulted in not only serious menace to the species, but also a failure of the water-holding, nutrient-retaining and topsoil-preserving capacity, thus losing the ecosystem capacity on which man depends.

Fragility by pollution

Environmental degradation not only negatively affects public health and stymies socioeconomic development, but also causes a great loss for biodiversity. In Yunnan biodiversity is also harmed and damaged by its environment pollution. Since 1950s, the ecological environment in Yunnan has steadily deteriorated, species loss accelerated and biodiversity declined because of its relative less-development and backwardness in economy, culture, science and technology. Some 615 tons of topsoil per km² run off from the Hengduanshan Mountains, and the 50 original plateau lakes with an area of over 1 km² in 1950s have been reduced to 30 at present. The population growth has resulted in excessive consumption of the natural resources and brought great pressure to physical environment. The medical plant species *Dendrobium candidum* under the second-class national protection is now highly endangered because of excessive collection for its high price. Deforestation and irrational logging have resulted in the loss, fragmentation or islandization of habitats. The establishment of cash crops such as rubbers, sugarcanes and various tropical fruit trees in the tropics in Southern and Southwestern Yunnan has caused the deforestation of the valuable tropical forests and rare tropical species loss (The State Environmental Protection Administration of China 1998, 2004). The pollution of soil, water and air has results in many environment-sensitive species, including the endemic *Cynops wolterstorffi*, *Sinocyclocheilus grahami grahami*, *Ottelia acuminata*, etc. from Lake Dianchi. Moreover, white spoonbills (*Platalea leucordia*) had overwintered in flocks on the swamp beaches of Lake Dianchi before, but none could be seen in the continual field observations in the last decade (Gao 2005).

Fragility by maladministration

Many people lack correct concept in significance and imminence of biodiversity conservation. In their daily production and life, many people focus on economic effects exclusively, rather than conservation, ecological effects or ecological ethics.

Biodiversity conservation funds are insufficient. Only the national nature reserves and some of the provincial ones have been funded for their capital construction while all the others have almost not been funded for their construction of basic facilities. Owing to the serious insufficiency in conservation funds and some other reasons, a great number of nature reserves in the province have not been substantially established or managed.

The management of import and export concerning wildlife is very difficult since the borderline between Yunnan and Myanmar, Laos and Vietnam runs very long. Owing to the specific location, Yunnan's biodiversity loses easily and frequently because large quantities of the wildlife are smuggled, trafficked, and speculatively traded at times. Butterflies in Xishuangbanna have ever been illegally captured and smuggled abroad. Certain people often secretly trade rare wildlife species of national protection

together with criminals at home and abroad for staggering profits. This greatly increases the difficulty in both the monitoring and management of the governments. In order to expand export, human activities, including overexploitation, blind production and illegal logging and hunting are increased in certain areas, so that the exhaustion of the wildlife resources is accelerated. Many rare wildlife resources are illegally sold and a number of valuable wildlife specimens are sold out as ordinary commodities at a very low price (Gao 2005). Furthermore, traditional slash-and-burn agriculture, frequent forest fires, serious forest pest attacks, illegal mining, excessive fishing, etc. are still major impediments to the biodiversity conservation.

Briefly, general lacks of sufficient funds, qualified protectors, advanced science and technology, and complete legal system for conserving biodiversity always result in a failure in both effective conservation and rational utilization of the biodiversity. The backwardness in science and technology for exploitation led to a very low utilization rate of resources (Wu *et al.* 1996). Neither invasion crises are appraised beforehand nor coordinative management systems are established when alien species are introduced. Necessary legal system for biodiversity conservation and utilization is still incomplete while the existing laws are not always strictly enforced to some extent.

Countermeasures

The above 8 major aspects of biodiversity and fragility in Yunnan have formed major challenges to the provincial biodiversity conservation and socioeconomic development. It is therefore imperative that proper measures should be taken for better conserving and utilizing biodiversity. Since Yunnan is relatively backward in socioeconomic development, however, it is faced with unprecedented dual pressures of biodiversity conservation and economic development. Between its economic development and biodiversity conservation, there is always an inevitable contradiction, which has long been an inextricable dilemma to perplex both researchers and decision-makers. Considering the importance of the problem and the fragility particularities of the province, 6 countermeasures have been suggested in a sustainable way to meet the needs of effective conservation of the biodiversity and socioeconomic development of the local rural communities on the basis of the theories of modern recycling economics, conservation biology, ethnobotany, technology innovation (Pu 1998), management creativity and certain successful experience.

Manpower cultivation

Hampered by lacks of qualified workers at various levels, Yunnan's biodiversity conservation should be supported by strengthening cooperation among the provincial government, the Chinese Academy of Sciences and some key universities for training more competent scientists and technicians. For a long-term purpose, the above institutions should be made greater contribution to both the environment conservation including biodiversity by forming adequate qualified manpower and sustainable development of physical environment, natural resources and social economy. This should also be supported by training the managers and administrators for their organizing and implementing various effective projects involving administration of both nature reserves and national parks, participation of the local people in the rural communities in social forestry, practical eth-

nobotany (Pei *et al.* 1998, 1998; Pei *et al.* 1998), sublimation of ethnical eco-ethics (Yu 1999), full comprehensive utilization of biological resources (Wu *et al.* 1996), sustainable uses of lands, environment protection and ecotourism for the improvement for their livelihood. The knowledge of modern forestry, natural ecosystems, rural socioeconomic development and practical managerial skills in practical sociology, finance, administration, and staff management should be effectively offered to the nature reserve staff, especially to the managers and administrators. Besides, cooperation between the province and some other key research institutions or universities at home and abroad should be wisely continued for more qualified workers and better implementation of projects for better biodiversity conservation and utilization.

Scientific monitoring

Since biodiversity is characterized by its dynamic features, basic investigations on the wildlife species of the whole province and their present distributions, rareness levels, endangerment intensity and exploitation values should be regularly made to update relevant data for timely programs of proper conservation and utilization. In accordance with the endemism, rareness and endangerment levels of the wildlife species in various ecosystems, few nature reserves should be established in major provenances to conserve their rare wild kindred species of cultivars or domestic animals. Meanwhile, a number of major facilities and gene pool should be planned and established for the wildlife species conservation *in vitro* (*ibid.*) for the sake of better preservation of animal genes, cells, tissues and organs as well as the conservation of peculiar and superfine genes. The management of development projects in traffic, mining, land, tourism, hydroelectricity and biological resources should further be enhanced and simultaneously appraisal systems of the environment should be strictly implemented to conserve all the nature reserves and other major protective areas of biodiversity such as wildlife habitats of both national and provincial levels without being arbitrarily ravaged.

Technology creativity

To monitor the population dynamics of any major wildlife species including the conditions of the population and their biohazards like forest fires and pests, it is necessary that a natural resource information system (NRIS) or geographic information system (GIS) be established for effective monitoring, decision and management. With greater intensity of inbreeding within a small population, its genetic heterozygosis decreases from generation to generation so frequently that the fitness of the population decreases and this always causes a final extinction of the population. Investigations on the small population viability probability of various wildlife species very urgently need to be strengthened since the destiny of a species ultimately depends on the viability of all the small populations of the same species. The minimum size for a livable population of all the species needs to be decided by further investigations and profound researches with the help of the NRIS or GIS. Besides, it is important that the palliation of species extinction rates of the families and genera with only one species should be emphatically studied. The habitat fragmentation, dynamic course of niche shifts, habitat heterogeneity, isolating extent of habitat spots, effects of edge and islandization, population survivorship and extinction dynamics, etc. should also be monitored and studied respectively. The lo-

calities, sizes, shapes and network connection of various sections should be profoundly approached, effective fire mantles and proper habitat corridors should be established so that the effects of habitat edges and fragmentation can be lessened. If any of the most important species fail to grow well in its original place, it should be removed and conserved in some other optimum habitats (Pu 2001).

This countermeasure should also be continuously implemented to make full use of the biodiversity because a gene may have a bearing on the rise and fall of a nation, a species may influence the economy of a country. And a good ecosystem is not only a good living environment of a region or a nation, but also a solid foundation for man's socioeconomic development recycling in a right direction (Gao 2005). It is important to discover the significant value of an excellent species or gene that will bring about some revolutionary changes in the industrial development such as food supply, medicines, agriculture, industry, etc. via the joint efforts made by the provincial government, scientific research institutes, universities, enterprises and the society (Pu 1998). Since exploitation and conservation of biodiversity are characterized by both conflicts and benefits to each other, the biodiversity should be not only well preserved, but also fully utilized for socioeconomic development via such joint efforts. With this measure implementation, the above tasks can be fulfilled.

Substitution exploitation

Yunnan is characterized by its ethnical cultural diversity because it has 25 minority nationalities in all except the Han, its ethnical cultural diversity is also an important kind of resources for socioeconomic development and biodiversity conservation. The major ethnical cultures in this specific region include the ancient bronze culture, Cuan culture, Dali culture of the Nanzhao Age, Yi's 10-month solar calendar culture, Mosuo's matriarchal culture, Naxi's Dongba culture with living hieroglyphics and arts, Dai's Beiye culture, Hani's terraced-fields culture, Bai's Benzhu culture and Tibetan's Kangba culture. As a matter of fact, all the 25 minority nationalities have their own specific ethnical cultures with strong attraction and distinctive ethnical features. Moreover, there are some other botanical cultures including ethnical tea culture, bamboo culture, flower culture, wine culture and diet culture as specific multi-nationality-permeating cultures, and geo-cultures of the borderland. All show Yunnan as one of the birthplaces of multinational cultures and man's civilization of the world (Pu *et al.* 2001).

Yunnan's ethnical cultural diversity evolved from the ethnical diversity has its unique functions, forming a useful means, strong force and ecological ethics for the socioeconomic and biodiversity sustainable development. By combining the ethnical cultural diversity with the biodiversity, it is possible that both the ethnical cultural and biological diversity be effectively conserved, mutually promoted and harmoniously developed (Chen *et al.* 1998). Great attention should be paid to the cultural diversity that should be intensively studied to conserve, utilize and manage the biodiversity. The public awareness for nature protection, the ethnical ecological ethics, environment consciousness, social customs, applied knowledge, valuable experience and reasonable suggestions of local people should be systematically summarized, properly sublimed and wisely adopted wherever they make sense according to the principles of conservation biology and ethnobotany (Liu *et al.* 1992, 1993; Long *et al.* 1994; Xu *et al.* 1995;

Wu 1997; Long *et al.* 1998; Pei *et al.* 1998; Pei 1998, 1998) in the development programs of local communities and the national objects of nature protection.

Cultures have been industrialized as a prospective industry with the acceleration of economic globalization. It is essential that the biodiversity should be effectively protected, but the rich multinational cultures and humanity resources deserve more to be fully exploited to support Yunnan's tourism because of their greater potentials and better prospects especially during the implementation of the national strategies of the development of West China. By taking the comprehensive advantages of these cultural legacies, physical environments and socioeconomic conditions in the exploitation, Yunnan's tourism can be further developed into a stronger economic mainstay supported by ecotourism through full utilization of the humanity resources including all the above ethnical cultures. When paying attention to the influences of economic globalization, proper peculiarities and singularities in the ethnical cultures should further be emphasized so that peculiar attraction of the ecotourism can be greatly enhanced, economic structures strategically reformed and socioeconomic development creatively improved.

Scientific development

Recycling economy, as a closed economic development pattern with the essence of ecological economy based on efficient and recycling utilization of resources, is a must for Yunnan in transforming the current economic development pattern, which is evidently flawed by huge waste, low output and high pollution. To conserve biodiversity and improve socioeconomic development effectively, a strategic target of building a resource-saving and environment-friendly society featuring sustainable development should be set promptly to control pollution and sustain economic growth in accordance with the scientific development concept in an all-round way. According to the strategic target, the current tapping measures should be innovated by emphasizing principle of equal importance on both exploitation and conservation of the resources, with priority given to conservation (Pu 1998). An ecological and harmonious Yunnan environment should be substantially clarified and established to construct an ecological agricultural system, a resource-saving depollution industrial system, an environment-friendly tourist system, a competitive technology innovation system and a strict legal execution system. Supported by the 5 systems, at least 5 mainstay industries, such as tobacco, pharmaceuticals, hydroelectricity, mining and tourism can be fostered successfully. Based on the implementation of proper policies of prices and taxes in favor of this endeavor, the consumption of energy, materials, water and over-dependence on the biodiversity can be reduced by means of efficient comprehensive utilization and recycling use of resources. Therefore, not only the ecological capital of the province won't be overdrawn, but also it will be balanced within this generation and more ecological capital will be reserved for the intergenerational development (Gao 2005).

As the five industries compose a complex set of systems involving socioeconomic sectors, enterprises, man and nature, an overall arrangement of each industry should be concordant with the arrangement of the provincial macro-system --- the construction of an ecological and harmonious Yunnan. The governmental departments of industry, agriculture, forestry, tourism, environment protection, education, judicature, as well as science and technology should be closely cooperated with various socioeco-

conomic sectors and rural communities. A people-oriented, comprehensive, harmonious and sustainable standpoint should be established to promote socioeconomic and human development in such an all-round way that urban, rural, regional, socioeconomic, harmonious development, and the harmony of man and nature, are taken into overall consideration. Further decisions should be scientifically made, the biodiversity conservation should be closely combined with the management system for biological resources, and the achievements of the governments at various levels should be strictly appraised in accordance with the criteria of the scientific-development viewpoint.

Institution arrangements

Institution arrangements should be implemented by enforcing the law strictly after establishing and perfecting a complete legal system for the provincial biodiversity conservation, so that the conservation could be legally managed (Pu 1996). The present regulations concerning the nature reserve conservation management should be more concrete, and further rules and regulations with good serviceability for the national and provincial nature reserves should also be formulated by the governments of various prefectures in which the reserves are located. Meanwhile the laws and regulations for biodiversity conservation and natural resource management should be strictly executed according to the requirements of the international Convention of Biodiversity Conservation and the related laws and regulations at home, so that the monitoring and supervision of the conservation status could be strengthened and those damaging biodiversity be dealt with or punished by law.

Biodiversity conservation should be financially programmed in the socioeconomic development planning of the governments at various levels to ensure the fund essential for both the conservation and management, construct the basic facilities for the conservation, strengthen the scientific and research capabilities in this field, and increase the levels of monitoring and management in the conservation. A foundation for the conservation should be gradually established by raising funds from all walks of life including industrial and commercial enterprises and non-governmental organizations. Cooperation of various kinds both at home and abroad should be extensively carried out to obtain more donations and supports so that more funds could be inputted for the biodiversity sustainable development.

Conclusions

An overall arrangement of the 6 countermeasures is a must and it lies undoubtedly in good cooperation of the governmental departments with various socioeconomic sectors and rural communities since biodiversity fragility improvement is a complex system-engineering project that involves so many factors such as physical environment, species evolution, human disturbances, management level, protection intensity, technology supports, etc. The 6 countermeasures should, therefore, be implemented in a harmonious way by establishing a mutual-improvement mechanism. It is thus necessary that proper institution guarantee mechanism covering legal, economic, political, administrative and cultural supporting systems be established and perfected. When tapping the existing natural resources, comprehensive utilization should be stressed (Wu *et al.* 1996) and intangible humanity landscape resources should be fully utilized with good protection of the biodiversity. Ecological education and natives'

participation in ethnic-featured cultural industry relevant to ecotourism as a substitute (Pu *et al.* 2000) for their over-dependence on natural resources should also be emphasized in the conservation practice. Attention should be paid to the entireness, comprehensiveness and systematization of the entire set of the countermeasures during their implementation. But for optimization of the 6 countermeasures in their organic entirety, a mutual-improvement mechanism cannot be established by making the 8 main aspects of biodiversity conservation better. In short, only by implementing all the countermeasures above well, can the biodiversity be protected, and socioeconomic sustainable development be realized.

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